Expanded Worldwide Ocean Optics Database

Jeffrey H. Smart
Johns Hopkins University/Applied Physics Laboratory
Johns Hopkins Rd
Laurel, MD 20723-6099
phone: (240) 228-4331 fax: (240) 228-6908 e-mail: jeffrey.smart@jhuapl.edu

Award #: N000140710257
http://wood.jhuapl.edu

LONG-TERM GOALS

The long-term objective is to provide a comprehensive worldwide optics database that includes data on a broad range of important optical properties, including diffuse attenuation, beam attenuation, and scattering. For the public version of the database, data from ONR-funded bio-optical cruises are given priority for loading into the database, but data from other scientific programs (NASA, NODC, NSF) and from other countries will also be routinely added to the Worldwide Ocean Optics Database (WOOD)[1]. For the operational Navy version of the database, forward area datasets, such as those collected in US Naval Oceanographic Office "military surveys" will be given priority.

OBJECTIVES

A main analysis objective in FY09, has been to determine whether radiative transfer theory can be used to accurately generate "Derived Parameters." A further objective is to provide data and algorithms having direct relevance to US Navy applications and needs. The US Navy has a special interest in locations such as the East China Sea, Yellow Sea, Gulf of Oman, and the Persian Gulf. As a result special attention has been given to testing the algorithms/software using data from such locations as well as to testing the methodology within nepheloid layers (sediment-laden bottom waters) due to the US Navy's plans to use optical sensors to detect bottom mines. Long term goals include acquiring and adding new optics data to WOOD, and to develop more automated procedures for ingesting new datasets, especially from high-density measurement systems like a glider or SeaSoar system[2]. Finally, assuring high data quality is a major objective, so substantial effort will be given to removing noise, calibration shifts, and other data artifacts from the data.

APPROACH

The overall approach is to develop a public database that shall be easy to use, Internet accessible, and frequently updated with data from recent at-sea measurements. The database shall be capable of supporting a wide range of applications, such as environmental assessments, sea test planning, and Navy applications. The database shall include derived optical parameters so that if measured data are not available, the user can obtain values computed from empirical algorithms (e.g., beam attenuation

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estimated from diffuse attenuation and backscatter data). Uncertainty estimates will also be provided for the computed results.

With regard to the use of radiative transfer theory to generate derived parameters, we are using multi-wavelength Satlantic SPMR, WETLabs AC-9, and Hobilabs HydroScat backscattering data to test radiative transfer inversion software. Essentially one uses a version of HydroLight to "invert" easily measured optical data [such as Apparent Optical Properties (AOPs), irradiance, and radiance], to obtain estimates of Inherent Optical Properties (IOPs). Data from a variety of seasons and locations are being tested in order to determine seasonal and geographic dependencies. Our focus is on the empirical relationships among the IOPs known as absorption (**a**), scattering (**b**), and total beam attenuation (**c**), and on the relationship of the various IOPs to the diffuse attenuation coefficient (K). The accuracy of each algorithm will be assessed in terms of absolute errors, such as the root-mean-square difference between measured and calculated values, and in relative terms such as the median absolute *percent* error. The absolute error is used to treat high or low values equally. The relative (percentage) error is used to account for the great variability in attenuation coefficient values as a function of depth.

WORK COMPLETED

The main thrusts of our work this past year involved:

1) building the initial transition version of "DoD-WOOD"
2) preparing/loading new bio-optical data into DoD-WOOD and into WOOD
3) developing software to improve the GUI, cleanse data, and to provide a hyperspectral editor
4) preparing and submitting a journal paper on DoD-WOOD
5) developing software to provide other US Navy agencies a copy of DoD-WOOD on DVD
6) collaborating with Eric Rehm U. Washington) who is running software that uses radiative transfer theory to compute derived optical properties.

The transition version of WOOD contains all the data in WOOD plus DoD-restricted More detailed descriptions of these accomplishments are included in the following paragraphs.

Building Transition Version of WOOD:

A fully-functional copy of WOOD was set up on an internal-to-APL server, and it has been populated with major "military survey" datasets from around the globe (see summary in Figure 1 and in Table 1). These DoD-restricted data were obtained primarily from the Naval Oceanographic Office (NAVOCEANO) and other US Navy projects. Besides the data indicated in Figure 1, another large compendium of WESTPAC data (Figure 2) is also being prepared and is nearly ready to be loaded.

New Data Added to WOOD:

With respect to the preparation and loading of new public datasets, the first two rows in Table 1 summarizes what has been accomplished since September 2008. The largest addition comes from NASA's SeaBASS[3] data acquired since January 2000 (SeaBASS data prior to Jan 2000 were already loaded into WOOD).

Table 1. Summary of Data Loaded in WOOD (first two rows) and into DoD-WOOD (all rows) during the past 12 months.

Data Description	***Example Numbers & Types of Profiles***
NASA SeaBASS (all data from Jan 2000 to June 2007)	~ 10,000 stations of World-wide multi-parameter bio-optical profiles (26 parameters: a, b, c, bb, Ed, Eu, Lu, Kd, Ku, PO4, Sal, temperature, etc.)
Gulf of Alaska Sep 1989 optics survey	K488, c490, angular backscatter (488 nm; 170 deg), temperature & salinity profiles [N = 27]
Persian Gulf NAVO March 1996 Optics data	Loaded 35 Kd profiles at 490 & 533 nm & 85 Ed profiles at 490 & 533 nm
Yellow Sea Oct 2002 SHAREM 142	profiles of c532, bb532, Kd & Ksys 532, CTD Temperature & Salinity [N=32]
Gulf of Oman April 1996 NAVO survey	CTD [N=25] & K490 [N=19] & Ed(lamda) & Lu(Lamda) [N=20] profiles
Yellow Sea July 2001 (620901):	AC9 profiles, aBeta bb532/"K"532, SPMR Kd491/510/533, & 121 CTD Temperature & Salinity profiles [N=105]
Persian Gulf NAVO October 2000 CTD/Optics survey	*Loaded 53 Hobilabs aBeta bb/KL profiles; SPMR Kd 488/532 nm; CTD T & sal [N=68]*
Gulf of Oman NAVO June-July 2000 CTD/Optics survey	Loaded Hobilabs aBeta bb/KL profiles [N=49]; SPMR Kd 490/510/533 nm [N=35]; Ed 456, 490/533 nm; CTD T & salinity [N=102]
NAVO South China Sea May/Jun 1997 SPMR/CTD survey	K, Ed, Lu versus wavelength and temperature/salinity profiles [N = 40]
NAVO South China Sea July 1998 SPMR/CTD survey	K, Ed, Lu versus wavelength and temperature/salinity profiles [N = 14]
NAVO South China Sea April 1998 SPMR/CTD survey	K491, 509, 533 nm [N = 34]and temperature/salinity profiles [N = 31]
NAVO North East Atlantic Jan-March 1989 optics survey	K, Ed, Es, Eu, Lu versus wavelength, cp660, and temperature profiles [N = 78]
NAVO North East Pacific Jun & Oct 1988 optics survey	K, Ed, Es, Eu, Lu versus wavelength, cp660, and temperature profiles [N = 55]
NAVO Barents Sea August 1989 optics survey	K, Ed, Es, Eu, Lu versus wavelength, c660, and temperature profiles [N = 9]

Ku & Kd are diffuse attenuation coefficients computed from upwelling (Eu) and downwelling (Ed) light, respectively. Es is downwelling surface irradiance, Lu is upwelling radiance, bb is optical backscatter, beam attenuation is “c”, and PO4 is phosphate.

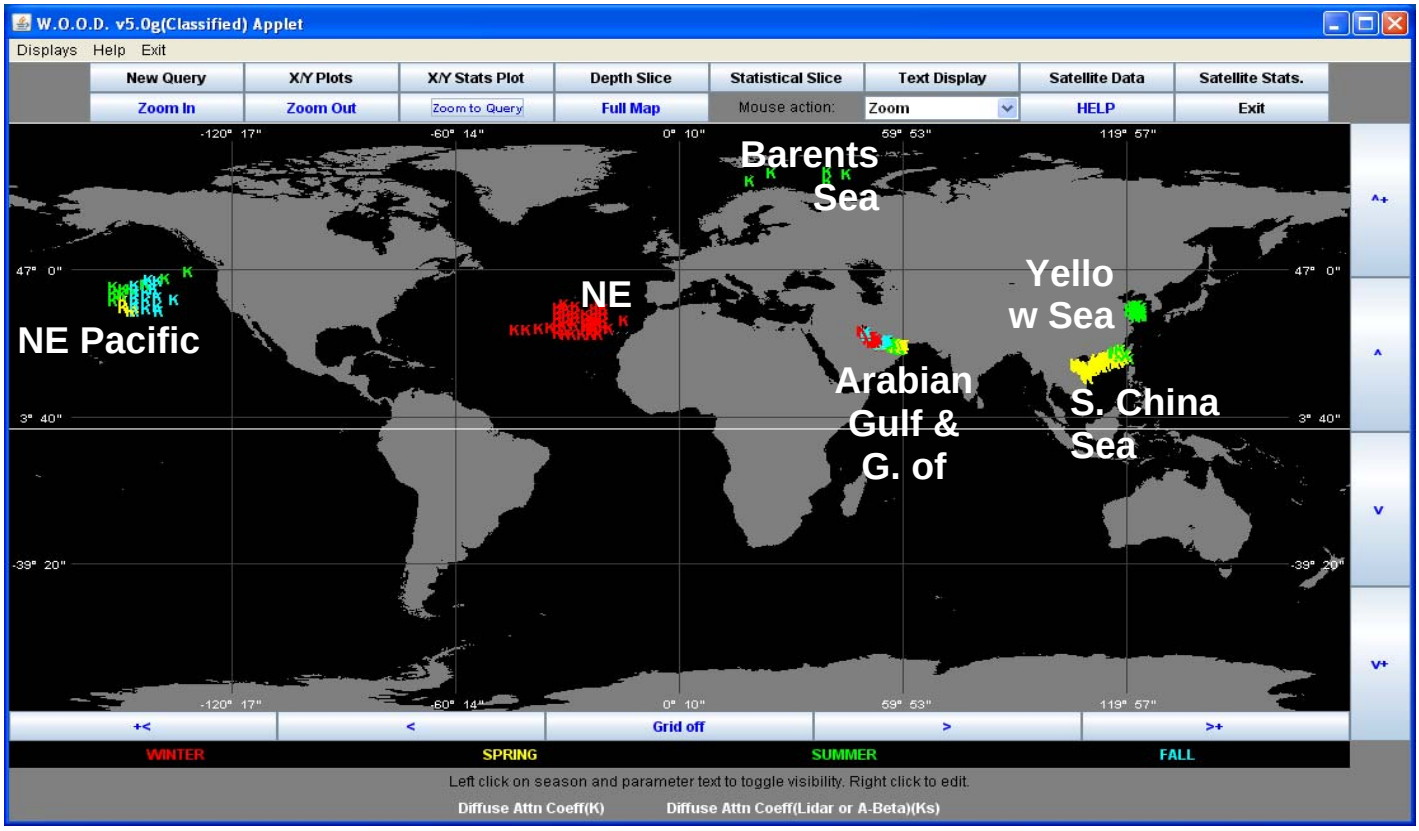

Figure 1. Map of DoD-restricted data in DoD- WOOD.[This map shows locations of K490 nm data in the NE Pacific, NE Atlantic, NW Pacific Oceans, in the Barents Sea, and in the Middle East.]

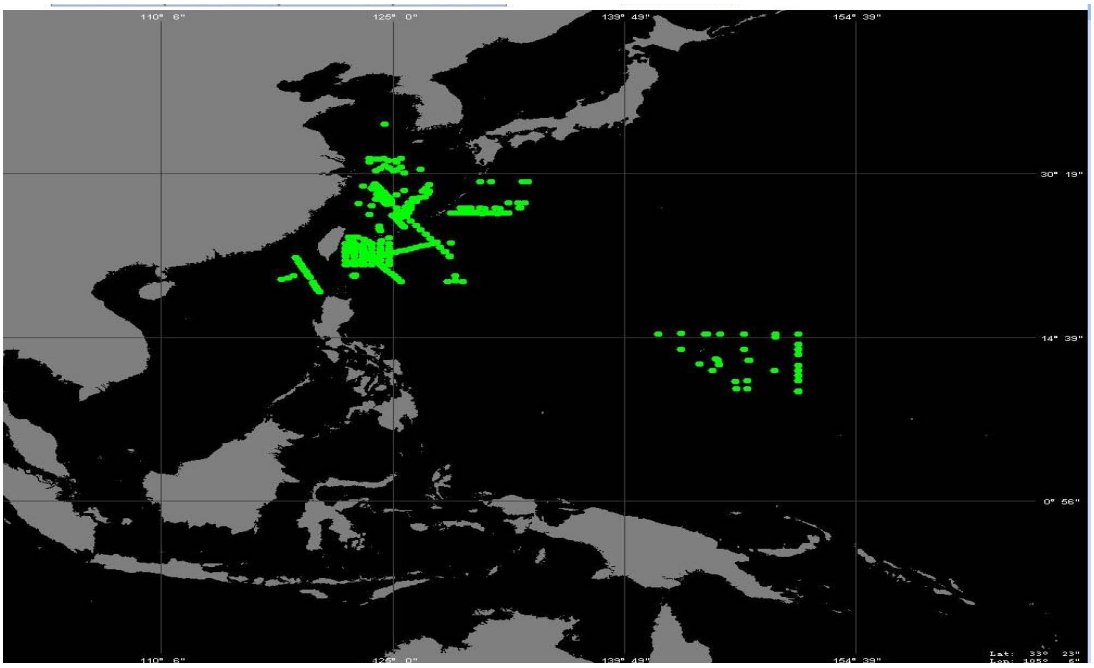

Figure 2. NW Pacific Data Being Prepared for DoD- WOOD. [Most of the profiles come from the continental shelf northeast of Taiwan, the South China Sea, or in the Philippine Sea east of Taiwan.

Software to Improve WOOD GUI and Data Quality Screening:
A high school mentor student developed a Java-based addition to the graphical user interface (GUI) that allows the user to summarize the yearly distribution of retrieved profiles. This feature enables the user to determine whether he/she has obtained a representative sampling from multiple years, or whether all the data come from only one (or just a few) years. A college intern wrote a Matlab-GUI-based editor program that facilitates screening of hyperspectral data, such as one obtains with the 100-wavelength "ac-s" being sold by WETLabs. This powerful editor automatically extracts representative wavelengths for initial viewing, but can apply the user's edits (such as interpolation across wild points and removal of spurious data regions) to other "nearby" wavelengths.

Software has also been developed to deal with the combination of data contamination through Raman scattering and data collected below a sensor's noise floor. As an example, Figure 3 shows raw and "cleansed" downwelling irradiance (Ed) data that is subsequently used to compute the downwelling diffuse attenuation coefficient (Kd).

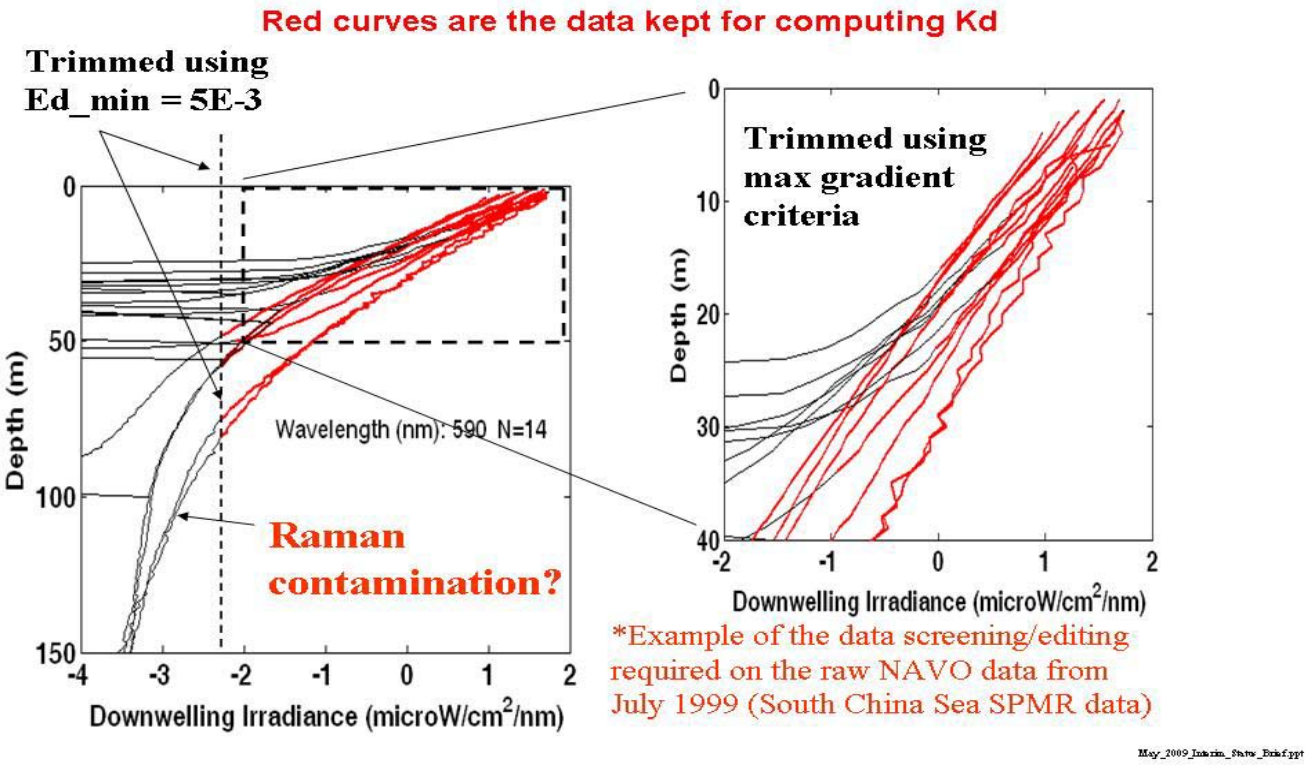

Figure 3. Gradient and Threshold-based automated editing of Raw Irradiance Data Contaminated by Sensor Noise and (apparently) Raman scattering. [The "bad" data are evidenced by an abrupt (and unrealistic) sudden decreases, or by a gradual roll-off that results in non-physical values of Kd.]

Preparing and Submitting a Journal Paper on DoD-WOOD:
In order to increase the awareness of the DoD-WOOD across the US Navy, a paper was prepared and submitted to the *Journal of Underwater Acoustics* for publication in a special non-acoustics issue. (The issue is due to be published in the Spring of 2010.)

Developing DVD-distributable version of DoD-WOOD:
In order to expand the utilization of the DoD-WOOD, software was developed to allow other US Navy agencies (such as NAVOCEANO or Office of Naval Intelligence) to build a local copy of the database using a single DVD provided by JHUAPL. It is anticipated that subsequent updates to the database will also be distributed on DVDs at least once or twice a year.

Empirical Algorithms:
Sample WOOD profile data from areas of naval interest (including the Yellow Sea, the Korean Straits, and the Sea of Japan) have been sent to Eric Rehm (University of Washington) to test the use of his radiative-transfer-based software for estimating depth profiles of multi-wavelength absorption (*a*), beam attenuation (*c*), backscatter (*bb*), and total optical scattering (*b*) from Ed(λ) and Lu(λ) depth profiles. Some significant results to date are as follows. First, using Ed and Lu, one can invert for *a* and *bb*, but not *b*. Second, because *c*(λ) is well defined spectrally (an inverse power law exists with respect to wavelength), a single measurement of c(λ), e.g., c(660 nm) from a standard beam transmissometer, can be used with a bio-optical model for *c*(λ) to derive profiles of *b*(λ).

RESULTS

Thousands of investigators from around the world have utilized the WOOD, which is routinely accessed by a wide variety of schools, colleges, universities, research institutes, and various DoD/US Government/State-Local Government agencies. Table 2 (shown on the next page) gives examples of DoD/US Government-related "hits" to the database.

As specific examples of US Navy use, the Environmental Support Systems Project within the SSBN Security Program used WOOD data to support eleven different classified tasks during GFY 2009. Analysts at NAVOCEANO Code NP33 (with whom the WOOD project maintains close ties) also uses WOOD for operational support to the Fleet. Finally, WOOD has been used to directly support our ONR sponsor, Dr. Steve Ackleson. For example, in 2005 he requested an analysis of the ~ 30,000 K profiles in WOOD that exist on the continental shelf in order to determine the fraction of the world's continental shelves that are sufficiently clear to allow a bottom-mounted sensor to measure downwelling radiance.

Table 2. Partial List of DoD/US Government -related & University "hits" to WOOD from July 2008 to September 2009

(Note: many "hits" come from obscure source such as "AT&T WorldNet Services" or "Verizon Internet Services Inc.")

- Naval Oceanographic Office
- National Aeronautics and Space Administration
- National Oceanic and Atmospheric Administration
- Navy Network Information Center
- Science Applications International Corporation
- U.S. Environmental Protection Agency
- U.S. Geological Survey

[209 total identifiable hits]

- Dalhousie University
- Hawaii Pacific University
- Johns Hopkins University/APL
- Monterey Bay Aquarium Research Institute
- Oregon State University
- Rice University
- Texas A&M University
- University of California, Santa Barbara
- University of Colorado
- University of New Hampshire
- University of Victoria
- University of Washington
- Utah State University

IMPACT/APPLICATIONS

WOOD is regularly used at JHUAPL to plan field exercises, support detectability studies, and conduct vulnerability analyses for the US Navy. In addition, the empirical relations derived under this grant have been used to provide critical input parameters to US Navy-related vulnerability modeling efforts. Beyond these immediate applications at JHUAPL, data from WOOD have been used by other DoD facilities and by graduate students working on dissertations. Furthermore, by requiring all projects funded by ONR's Ocean Optics Program to submit their data to the WOOD, ONR is ensuring that these valuable data continue to be available for current and future investigators. It is estimated that the availability of a single location, uniform-format optics database has saved the US Navy many thousands of dollars in test planning and other naval applications. By providing the Navy and the research community with this resource, both types of users benefit from improved knowledge of the optical properties of the ocean. Access to historical optics data can also be useful for assessing newly acquired data. The two can be compared to see if the new results are atypical, and if so, one might go on to determine the cause (e.g. unusual forcing conditions, influx of a different water mass, or perhaps even an instrument calibration problem).

TRANSITIONS

The SSBN Security Program has added DoD-WOOD to its suite of environmental databases that it maintains under the Environmental Support System (ESS) Project at JHUAPL. The entire contents of WOOD, along with its wide array of graphical displays, satellite climatologies, and statistical outputs, have been copied to this clone of WOOD which will be regularly augmented with various DoD-restricted and classified datasets. A full copy of DoD-WOOD is being sent to NAVOCEANO, and other agencies (such as NAVAIR and ONI) have expressed interest in obtaining a copy as well.

RELATED PROJECTS

The project's Principal Investigator, Jeff Smart, is involved with several projects that regularly use DoD-WOOD data to plan US Navy field tests and to conduct vulnerability studies. Mr. Smart is a also associated with the ONR Littoral Warfare Advanced Development (LWAD) project that conducts numerous at-sea tests, including tests involving optics in overseas areas of special interest to the US Navy. Via the LWAD project, the WOOD project has obtained important optical data in the East China Sea, the Philippine Sea, and the Yellow Sea. WOOD also provides LWAD with optics data for test planning purposes. The Applied Physics Laboratory works closely with the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS) community in order to ensure that their bio-optical data are regularly added to the WOOD. In order to foster this relationship, US Navy permission was obtained to provide unclassified LWAD optics data (collected by JHU/APL scientists) to SeaBASS.

PUBLICATIONS

Smart, J.H. and K.T. Barrett, "Data-thinning Algorithms for "Over-Sampled" Multi-Parameter Ocean Optics Data," *Optics Express*, Vol. 16, No. 26, pp 21423-21433 (22 December 2008)

"World-wide Ocean Optics Database for DoD Applications," submitted to *Journal of Underwater Acoustics* [in review]

REFERENCES

[1] WOOD Website: http://wood.jhuapl.edu

[2] SeaSoar Website: http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm